PAP-489

TRINITY DAM AUXILIARY OUTLET WORKS
ADDITIONAL LABORATORY INVESTIGATIONS

BY

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PAP-489

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Form DFC-11
(10-51)
Bureau of Reclamation

INFORMATIONAL ROUTING

FEB 0 5 1986

D-1531

Memorandum

To: Regional Director, Sacramento, California
Attention: MP-400

From: FOR Chief, Division of Research and Laboratory Services

Subject: Trinity Dam Auxiliary Outlet Works - Additional Hydraulic Laboratory Model Results
(Your Letter Dated September 19, 1985, to Chief, Division of Water and Land Technical Services, Attention: D-430, and Enclosed Memorandum From Project Superintendent, Redding, California, Dated September 10, 1985)

GPO 852320

At your suggestion, we have conducted additional hydraulic model studies of the Trinity Dam auxiliary outlet works. The additional studies included:

1. Removal of the 1/2-inch offset orifice ring from the upstream edge of the air slot and the installation of a 6-inch offset 20:1 ramp on the downstream edge of the air slot.

2. Removal of all offsets and the air slot downstream of the jet-flow gate (original design configuration).

3. The installation of a larger deflector plate, 2-feet deep and 12-feet long, on the inside of the Trinity Dam spillway tunnel opposite the auxiliary outlet conduit entrance.

4. Removal of the aluminum air duct from the vertical curve section of the auxiliary outlet works conduit.

5. Measurements to obtain data in order to estimate forces against the deflector plate and the air duct system.

From the additional studies we have determined the following:

1. The 6-inch offset 20:1 ramp modification downstream of the air slot will not provide satisfactory flow conditions for gate openings greater than 70 percent. The water flow deflects upward off of the 20:1 ramp. The impingement of the water flow against the top of the conduit increased compared to the the 1/2-inch orifice ring alternative at the 100 percent gate opening.

2. A certain amount of water flow impingement to the top of the conduit at all gate positions is inherent in the design of the Trinity Dam auxiliary outlet works facility.

3. A larger deflector plate could be installed on the inside of the spillway tunnel opposite the auxiliary outlet conduit. The larger deflector plate would provide added protection to prevent return flow from forming a roller inside and at the end of the conduit. However, we recommend the deflector plate not be greater than 2 feet deep by 12 feet long compared to a minimum size of 15 inches by 8 feet long.

4. Removing the air duct from the vertical curve section of the conduit is not recommended. The conduit will prime itself at the 30 to 40 percent gate opening flow conditions. Very turbulent flow and vapor pressure will occur immediately downstream of the jet-flow gate. Major failure of the conduit lining and air duct system could result when the conduit is primed.

The 6-inch offset 20:1 ramp downstream at the air slot will not provide satisfactory flow conditions at the 100 percent gate opening. Therefore, we recommend that the 1/2-inch offset ring on the upstream edge of the air slot alternative be used as we reported in our memorandum to you dated August 30, 1985.

A more detailed discussion on the results of the additional hydraulic model studies is included as an enclosure to this memorandum.

We would be happy to discuss the results of the additional studies made to the Trinity model with project personnel at their convenience.

H. Walter Anderson

Enclosure

Copy to: Regional Director, Sacramento, California, Attention: MP-200, MP-430
Project Superintendent, Redding, California
Chief, Division of Water and Land Technical Services, E&R Center
(with enclosure to each)

Blind To: D-430
D-220
D-223 (Gray)
D-1500
D-1530
D-1530A
D-1531 (PAP file)
D-1531
(with enclosure to each)

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TRINITY DAM AUXILIARY OUTLET WORKS
ADDITIONAL LABORATORY INVESTIGATIONS

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PURPOSE

Additional investigations of the 1:14.87 scale hydraulic model of the Trinity Dam Auxiliary Outlet Works were made to determine if the impingement of water flow onto the air duct system could be reduced.

INTRODUCTION

Previous hydraulic model studies (reported by memorandum to the Regional Director, Sacramento, California, Attention: MP-400, dated August 30, 1985) recommended a 1/2-inch offset orifice ring on the upstream edge of the air slot. The 1/2-inch orifice ring will cause flow to deflect upward onto the bottom of the air duct system. The worst condition is at the 40 percent gate opening where the flow starts impinging onto the air duct about 20 feet and ends about 40 feet (prototype) downstream of the air slot. The flow in the impingement area was well aerated with heavy wave action and did not completely seal off the upper portion of the conduit.

As an alternative to the 1/2-inch offset orifice ring on the upstream edge of the air slot, a 6-inch offset 20:1 ramp downstream of the air slot, as shown schematically in figure 1, was investigated. The downstream offset ramp overall performance, from 0 to 70 percent gate opening flow conditions, is better compared to the 1/2-inch orifice ring. From 70 to 100 percent gate opening, the performance is about the same except water flow impingement to the top of the conduit increased significantly. From 70 to 100 percent gate openings, the water flow from the jet flow gate deflects off of the 20:1 ramp upwards onto the bottom of the air duct. The flow in the impingement area was a solid column of water. The upward impingement was more severe compared to the 1/2-inch orifice ring flow condition at the 100 percent gate opening.

It was of interest to determine the degree of water flow impingement onto the bottom of the air duct system as the auxiliary outlet works was originally designed. An investigation was made without the air slot, the upstream orifice ring, and downstream offset-ramp modifications. At the 100 percent gate opening, water flow will impinge onto the bottom of the air duct system. The impingement is very similar to the flow conditions observed for the 1/2-inch orifice ring from the 70 to 100 percent gate openings. At lower gate openings, from about the 20 to 70 percent range, wave action on top of the flow will periodically have an amplitude high enough to make contact with the bottom of the air duct as the wave travels down the conduit for the entire length. Therefore, it appears that impingement of water flow onto the bottom of the air duct system is inherent in the design of the auxiliary outlet works.

The 1/2-inch offset orifice ring and air slot were reinstalled and the air duct aluminum tubing on the vertical curve section of the conduit was removed. The purpose of removing the air duct section was to determine if the length of the air duct could be shortened in order to reduce the cost of installation. However, test runs established that the conduit would prime itself at the 30 to 40 percent gate opening flow conditions. The periodic high amplitude wave that travels downsteam on top of the main water flow would close off the air supply coming from the spillway tunnel. When the wave was large enough, the blockage of air supply would be sufficient that the conduit would prime itself. Very turbulent flow conditions and vapor pressures (prototype) were observed immediately downstream of the jet-flow gate when the conduit is primed and running full of water. Therefore, the length of the air duct cannot be shortened.

A larger deflector plate was installed inside the spillway tunnel opposite the conduit as shown in figure 2. The larger deflector plate, 2 feet deep by 12 feet long, was 50 percent larger than that recommended and tested in the previous investigation reported by the memorandum of August 30, 1985. At the 100 percent gate opening, the larger deflector plate appears to provide about twice as much protection against the return flow from forming a roller inside the conduit. The deflector plate should not be larger than 2 feet deep by 12 feet long. A plate deeper than 2 feet may catch the peaks of the water waves as they enter the spillway tunnel from the conduit. A longer plate will not provide additional protection.

Pitot tube measurements were made of the water flow near the underside of the air duct at the end of the steel lining and at the deflector plate inside the spillway tunnel. The pitot tube measurements provided data from which forces against the underside of the air duct and against the deflector plate could be estimated for structural design purposes.

Subsequent paragraphs discuss in greater detail the test results of (a) the downstream 6-inch offset 20:1 ramp modification, (b) without the air slot configuration, (c) shorter air duct system, and (d) the estimated forces for design purposes. Conclusions are then offered.

TEST RESULTS

General

It is assumed the reader is familiar with the test program and the test results as reported by memorandum dated August 30, 1985. Therefore, a detailed description of the hydraulic model, the test program and results including the basis for previous conclusions will not be repeated in this report.

Downstream 6-inch Offset 20:1 Ramp Modification

Figure 1 shows schematically the downstream offset ramp configuration investigated as an alternative to the upstream 1/2-inch offset orifice ring. The results of the downstream offset ramp modification compared to the upstream 1/2-inch ring can be observed in figures 10, 11, 13, and 15 (these figure numbers correspond to the same figures included in the August 30, 1985 memorandum report).

Figure 10 illustrates that the air demand is considerably less for the downstream offset ramp configuration compared to the 1/2-inch ring for the 0 to 70 percent gate openings. The air demand is slightly greater for gate openings 70 to 100 percent. The side wall pressures are less negative from 0 to 50 percent gate openings as shown in figure 11. The side wall pressures are more negative for gate openings above 50 percent, particularly, immediately downstream of the air slot, figure 11(a), when the gate opening is 70 percent as compared to the 1/2-inch ring.

The invert pressures shown in figure 13, are less negative downstream of the air slot below gate openings of 50 percent but are slightly more negative for gate openings above 50 percent. The invert pressures upstream of the air slot are more positive below the 40 percent gate opening and less positive above compared to the 1/2-inch ring.

Figure 15 also illustrates that the air demand is considerably less below gate openings of 70 percent for the downstream offset ramp compared to the upstream 1/2-inch ring. The air demand is slightly higher for the gate openings above 70 percent.

Overall performance of the downstream offset ramp is satisfactory and in many respects it is better than the upstream 1/2-inch offset orifice ring. However, at flow conditions above the 70 percent and particularly at the 100 percent gate opening, water flow deflected upwards off of the 20:1 ramp onto the bottom of the air duct. The degree of impingement increased substantially, figure 3, at the 100 percent gate opening. Also, the flow in the impingement area was a solid column of water such that the impingement was continuous, i.e., without periodic wave action or air pockets as compared to the 1/2-inch ring, figure 4. This action can best be observed by viewing the comparison of the video tapes made for both alternatives. Copies of the video tapes including the additional investigations have been sent to the Regional Director, Sacramento, California, Attention: MP-200 and to the Project Superintendent, Shasta Dam, Redding, California.

Without Air Slot (Original Design)

The Trinity Dam auxiliary works was originally designed without an air slot or offsets to provide aeration of the jet-flow downsteam of the jet-flow gate. The Trinity hydraulic laboratory model was modified by removing the downstream offset ramp (the upstream orifice ring was already removed) and filling in the air slot with automotive body filler. The air slot was filled in, and sanded smooth, up to a level about 8 feet above the invert. Air could still enter into the conduit through the upper unfilled air slot from the air scoop. Also, water could splash back into the air scoop at this location.

The purpose for investigating the auxiliary outlet works as originally designed was to observe the water surface profile and determine if water flow impinged onto the bottom of the air duct system. At all gate positions, a certain amount of water impingement occurs. At the low gate positions, the impingement is in the form of heavy water spray. At the mid-gate positions, the impingement is from periodic wave action that develops from the outlet flow characteristics of the jet-flow gate. These periodic waves travel the entire length of the conduit at the same velocity of the main water flow. At the 100 percent gate opening, the very top of the main water flow continuously impinges onto the bottom of the air scoop immediately downstream of the jet-flow gate. Heavy wave action up against the bottom of the air duct extends downstream about 60 feet from the jet-flow gate. The continuous impingement and heavy wave action can be significantly reduced by lowering the gate to the 90 percent opening. However, the periodic wave action remains and continues for the entire length of the conduit. It appears that water flow impingement onto the bottom of the air duct system is inherent in the design of the jet-flow gate and the conduit.

The impingement characteristics observed, without the air slot, are very similar to those observed with the 1/2-inch ring air slot modifications for the 70 to 100 percent gate opening range. The impingement characteristics, with the 1/2-inch ring air slot configuration, were more severe for the lower gate positions. These comparisons can best be observed by viewing the video tapes.

The results of the test runs, without the air slot, are included in figures 10, 11, 13, and 15. The major difference is that the air demand, figure 15, is slightly less than the downstream offset ramp configuration. The smaller air demand results from the removal of the air slot. Air is not being entrained into the main water flow. Therefore, the potential for cavitation damage is not being reduced. The slightly smaller air demand may also indicate that the downstream offset ramp configuration is not as efficient as the upstream 1/2-inch offset orifice ring, also shown on figure 15, for aerating the main water flow. The upstream 1/2-inch offset orifice ring air slot configuration would have a higher potential for reducing cavitation damage because more free air is entrained into the main water flow.

Without Air Duct

The aluminum air duct tubing was removed from the Trinity model on the vertical curve section of the conduit. The purpose of removing the lower section of air duct was to determine if the auxiliary outlet works could be operated safely with a shorter length of air duct, thereby reducing its cost of installation. The upstream 1/2-inch offset orifice ring, air slot, sealed bulkhead, and the deflector plate modifications (recommended in the August 30, 1985 memorandum) were installed for this investigation.

At the 30 to 40 percent gate opening range, the conduit primed itself. The prime was caused by the periodic wave action against the top of the conduit on the vertical curve section. The wave action closed off the air supply. The priming action was sudden and was completed almost instantaneously. After the prime was completed, the conduit flowed full except at the very lower end. Very turbulent flow occurred immediately downstream of the jet-flow gate. The prime evacuated all of the water manometers which indicates that vapor pressure would occur inside the prototype conduit. The priming action was videotaped.

The flow conditions for the primed conduit could cause major failure of the lining and air duct system and would be an unsafe operation. Therefore, the length of the air duct system cannot be reduced.

Dynamic Forces

Pitot tube measurements were taken in order to estimate the dynamic forces acting against the bottom of the air duct and against the spillway tunnel deflector plate. The estimated dynamic forces can be used for design purposes. The estimated forces are based on the recommended 1/2-inch offset orifice ring upstream of the air slot, a sealed bulkhead at the end of the air scoop, and a deflector plate installed inside the spillway tunnel.

Spillway tunnel deflector plate. - The maximum velocity head measurement of the return flow against the deflector plate occurred near the inside surface of the spillway tunnel lining, at a point 4 feet upstream from the downstream edge of the larger deflector plate shown in figure 2. The maximum velocity head was 34.1 feet of water (all values stated hereafter are prototype). The maximum velocity of the return flow on the inside surface of the spillway tunnel based on this velocity head measurement would be about 47 feet per second. At a distance of 0.93 feet (measured radially into the tunnel from the inside surface of the lining) the velocity head of the return flow was zero. Therefore, there was no return flow 0.93 feet from the inside lining surface.

The maximum average force of the return flow against the upper 0.93 feet of the deflector plate based on the rate of change in momentum is estimated to be about 900 pounds per linear foot. The maximum force which occurs at the very top of the deflector plate is estimated to be about 2,000 pounds per linear foot. The dynamic force on the deflector plate below the upper 0.93-foot distance is essentially zero.

The deflector plate could also be subject to wave action forces when the spillway tunnel is discharging flood flows. The maximum velocity for the maximum spillway tunnel discharge of 24,000 cubic feet per second would be 125 feet per second (Trinity Dam Spillway, HYD-447). It is estimated that the maximum wave action force from the spillway flow would be about 210 pounds per square inch and would occur longitudinal to the spillway tunnel axis.

Air duct system. - The maximum impingement of the deflected flow, from the 1/2-inch orifice ring, onto the air duct system occurs at the 40 percent gate opening, near the end of the air scoop about 30 feet downstream from the jet-flow gate. The main impingement of the deflected flow extends upstream and downstream about 8 feet for a total length of 16 feet. A pitot tube measurement was made at this location at an elevation even with the bottom of the air scoop. The maximum measurement was +41.4 feet and occurred at an angle of 11° below the horizontal. The static water pressure inside the conduit at the piezometer P10 location was -12.7 feet (August 30, 1985 memorandum report). Therefore, the maximum velocity head measured was +54.1 feet of water. The calibrated discharge of the jet-flow gate at 40 percent open is 1,425 cubic feet per second. Based on this information and using the rate of change in momentum principle, the upward force perpendicular to the air scoop is estimated to be 2,000 pounds per linear foot in the impingement area.

It appears the major wave action force along the axis of the conduit would occur at the 100 percent jet-flow gate opening. The calibrated discharge at 100 percent gate opening is 2,936 cubic feet per second with a maximum velocity of about 90 feet per second. The wave action force from the conduit flow is estimated to be about 110 pounds per square inch and would act against any object hanging vertically down from the bottom of the air duct system or perpendicular to the water flow.

The drag force on the bottom of the air duct system would be similar to the drag force on a ship's hull. The drag coefficient is estimated to be 0.0016 (Elementary Mechanics of Fluids by Rouse, 1946). Using the basic drag equation, the drag force is estimated to be about 15 pounds per linear foot.

The maximum pressure differential between the inside of the air duct and the inside of the conduit can be determined from figures 10 and 11. At the 40 percent gate opening, the maximum positive pressure differential (from inside to outside of the air duct) was -10.64-(-11.85) = +1.21 feet of water (+2.8 pounds per square inch) taken from figures 10 and 11(a). At the 70 percent gate opening, the maximum negative pressure differential was -8.98-(-1.96) = -7.02 feet of water (-16.2 pounds per square inch) taken from figures 10 and 11(b).

CONCLUSIONS

Based on the results of the additional hydraulic model studies, the following conclusions are made:

1. The 6-inch offset 20:1 ramp downstream of the air slot increases water flow impingement onto the bottom of the air duct system for the 70 to 100 percent gate opening range. The water flow impingement at the 100 percent gate opening is more severe compared to the 1/2-inch offset orifice ring upstream of the air slot. Therefore, the downstream offset ramp configuration is not recommended.

2. Water flow impingement to the top of the conduit occurs at various degrees for all gate openings, and appears to be inherent in the design of the Trinity Dam auxiliary outlet works. There does not appear to be any technique or configuration that can easily modify the basic design that would completely eliminate water flow impingement onto the bottom of the air duct system.

3. The removal of the offsets and the air slot downstream of the jet-flow gate will minimize the water flow impingement against the bottom of the air duct. However, without an air slot configuration, air entrainment into the main water flow column will not occur. Therefore, the potential for cavitation damage downstream will not be reduced. The best alternative for air entrainment is the 1/2-inch offset orifice ring upstream of the air slot (including the other modifications recommended in the August 30, 1985 memorandum).

4. A shorter air duct will cause the conduit to prime itself. Very turbulent flow conditions and vapor pressure will occur immediately downstream of the jet-flow gate. The result will be an unsafe operation. Therefore, a shorter air duct is not recommended.

5. Added protection against the formation of a roller on top of the main water flow at the end of the conduit will occur with the installation of a larger deflector plate inside the spillway tunnel opposite the conduit entrance. However, the depth of the deflector plate should not be greater than 2 feet. A length longer than 12 feet is not necessary.

6. The maximum dynamic force against the deflector plate from the return flow on the spillway tunnel lining is estimated to be about 2,000 pounds per linear foot at the very top. The maximum average force is estimated to be about 900 pounds per linear foot. The longitudinal force caused by spillway discharge is estimated to be about 210 pounds per square inch.

7. The maximum upward dynamic force against the bottom of the air duct is estimated to be 2,000 pounds per linear foot in the impingement area for the 40 percent gate opening flow condition. The main impingement area occurs near the end of the steel liner over a length of 16 feet. The maximum force against the surface of any object perpendicular to the conduit flow is estimated to be about 110 pounds per square inch. The drag force against the bottom of the air duct system is estimated to be about 15 pounds per linear foot. The maximum pressure differentials between the inside and outside of the air duct is estimated to be about +2.8 and -16.2 pounds per square inch.

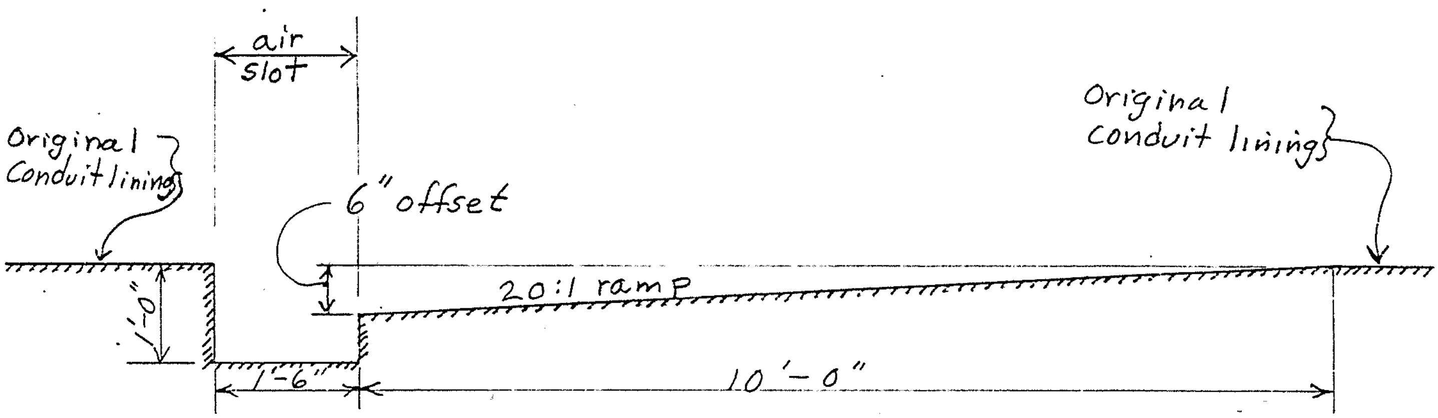


Figure 1 - Trinity Dam Auxiliary Outlet Works cross-section of downstream offset-ramp alternative

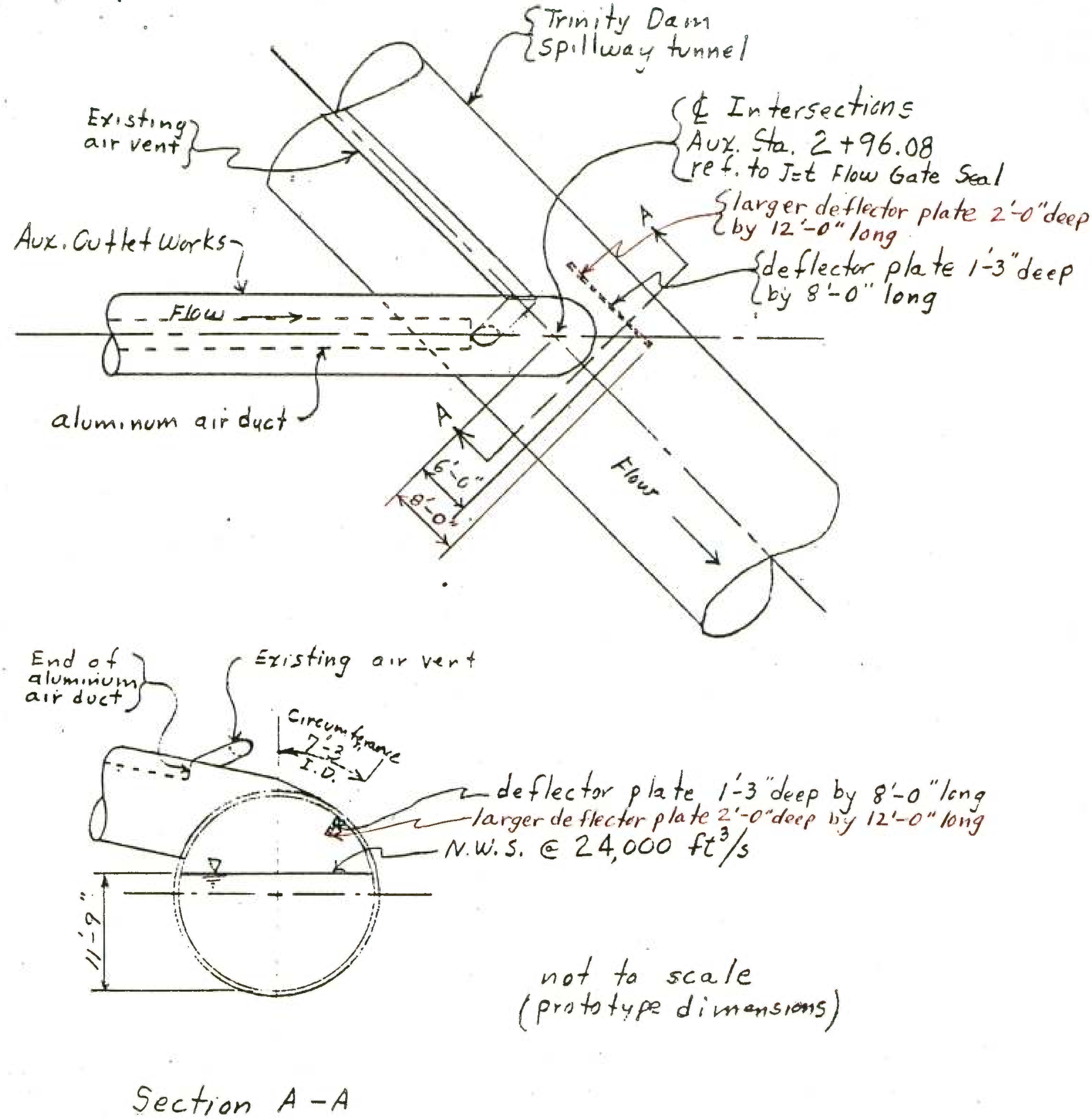


Figure 2- Larger deflector plate location compared to smaller deflector plate installation

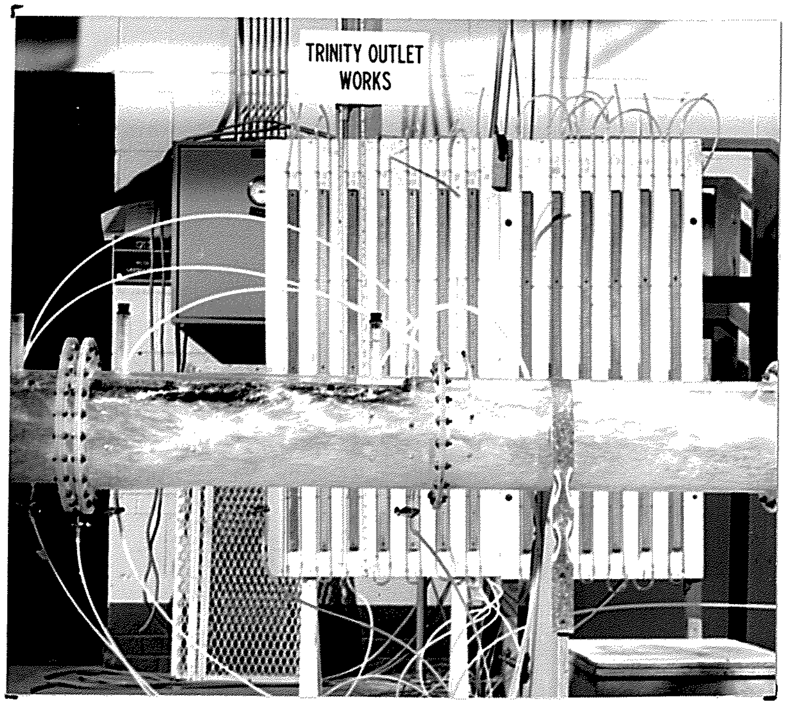


Figure 3. - View of downstream 6-inch offset 20:1 ramp alternative showing upward water flow deflection off of the ramp at 100 percent gate opening flow conditions.

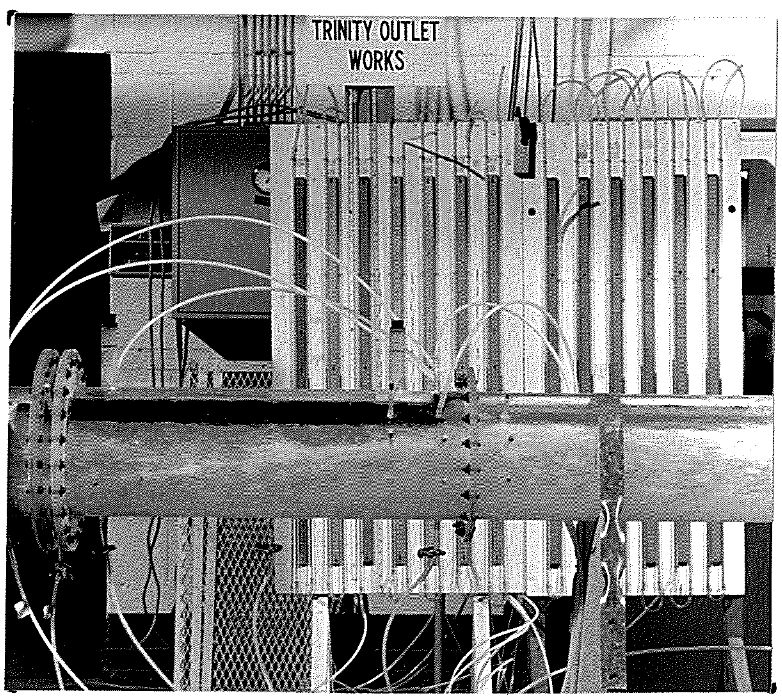


Figure 4. - View of upstream 1/2-inch offset orifice ring modification showing water flow impingement onto bottom of the air duct at 100 percent gate opening flow conditions.

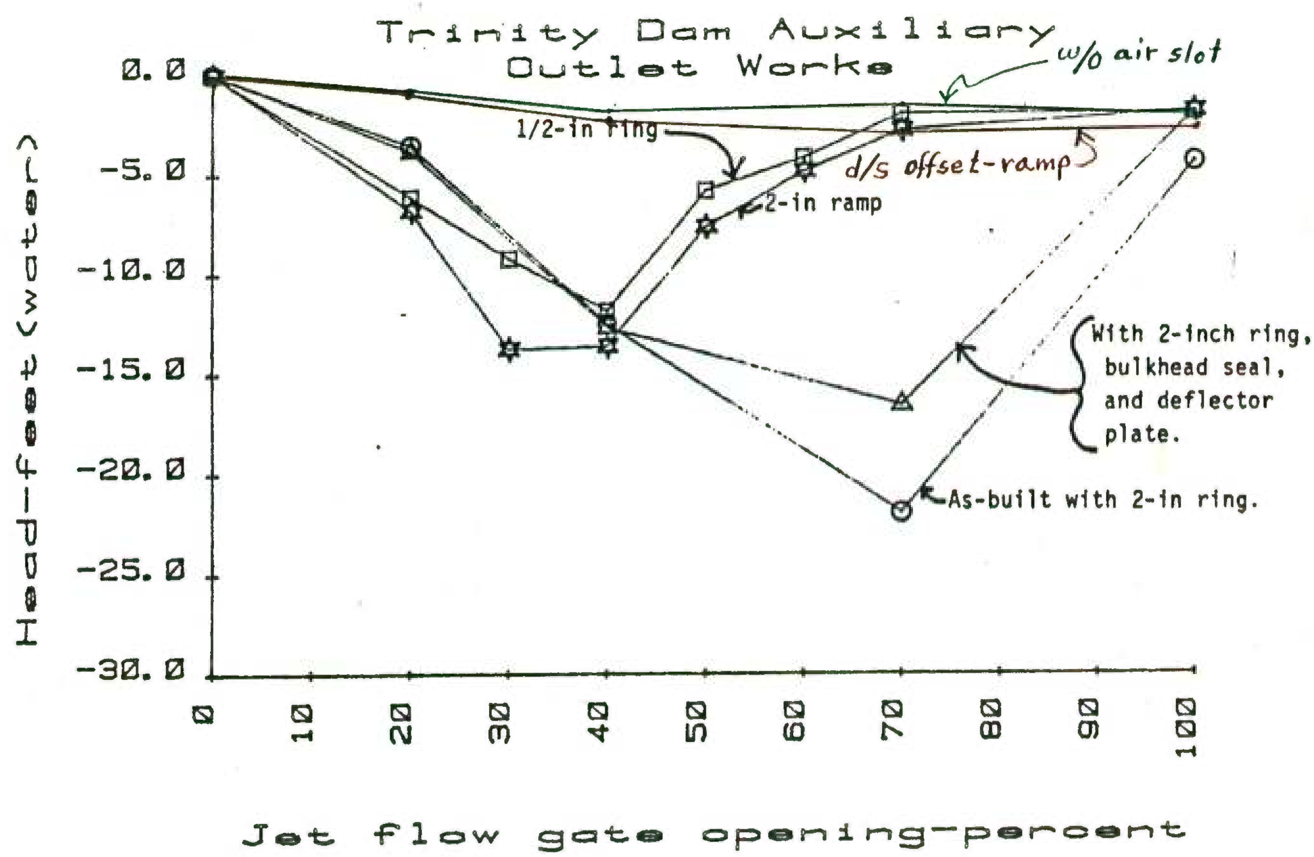
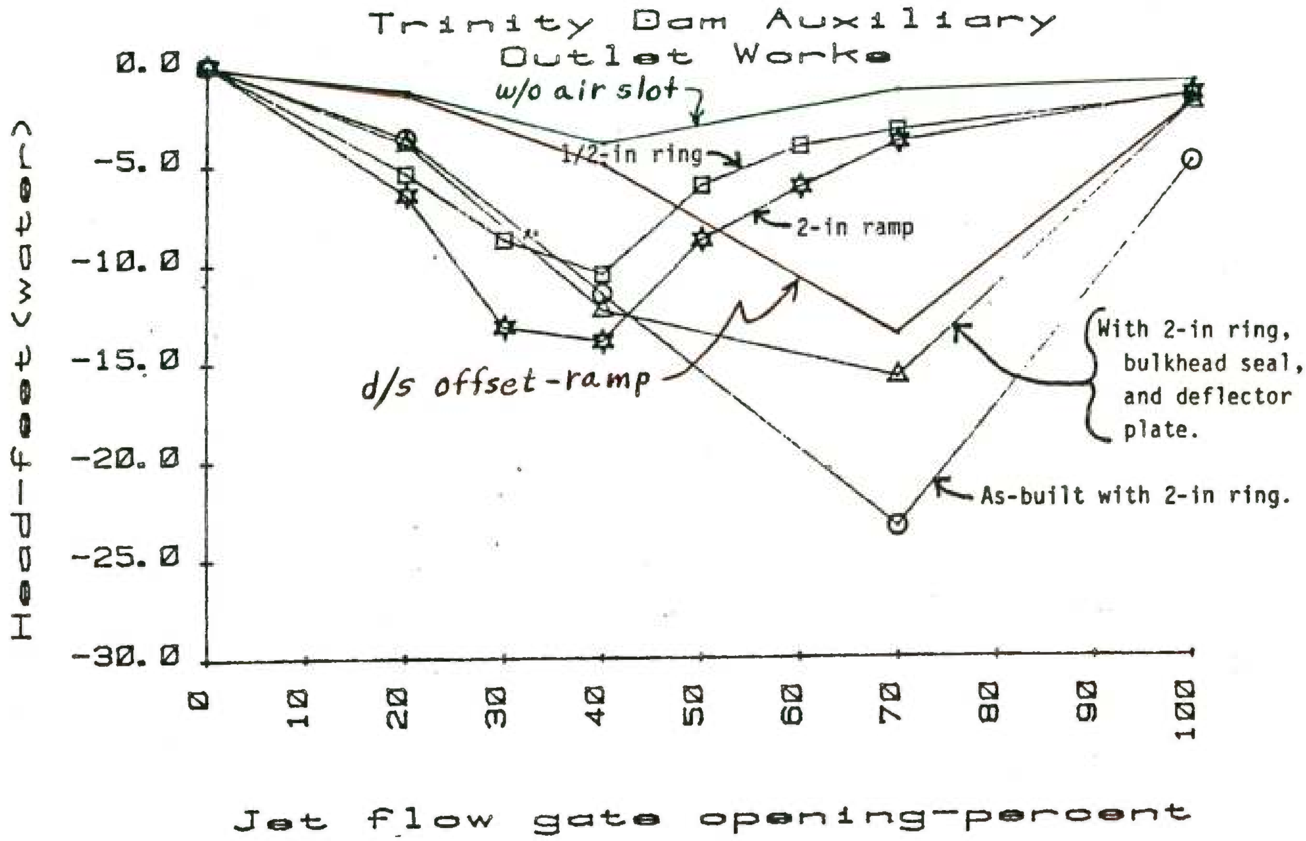
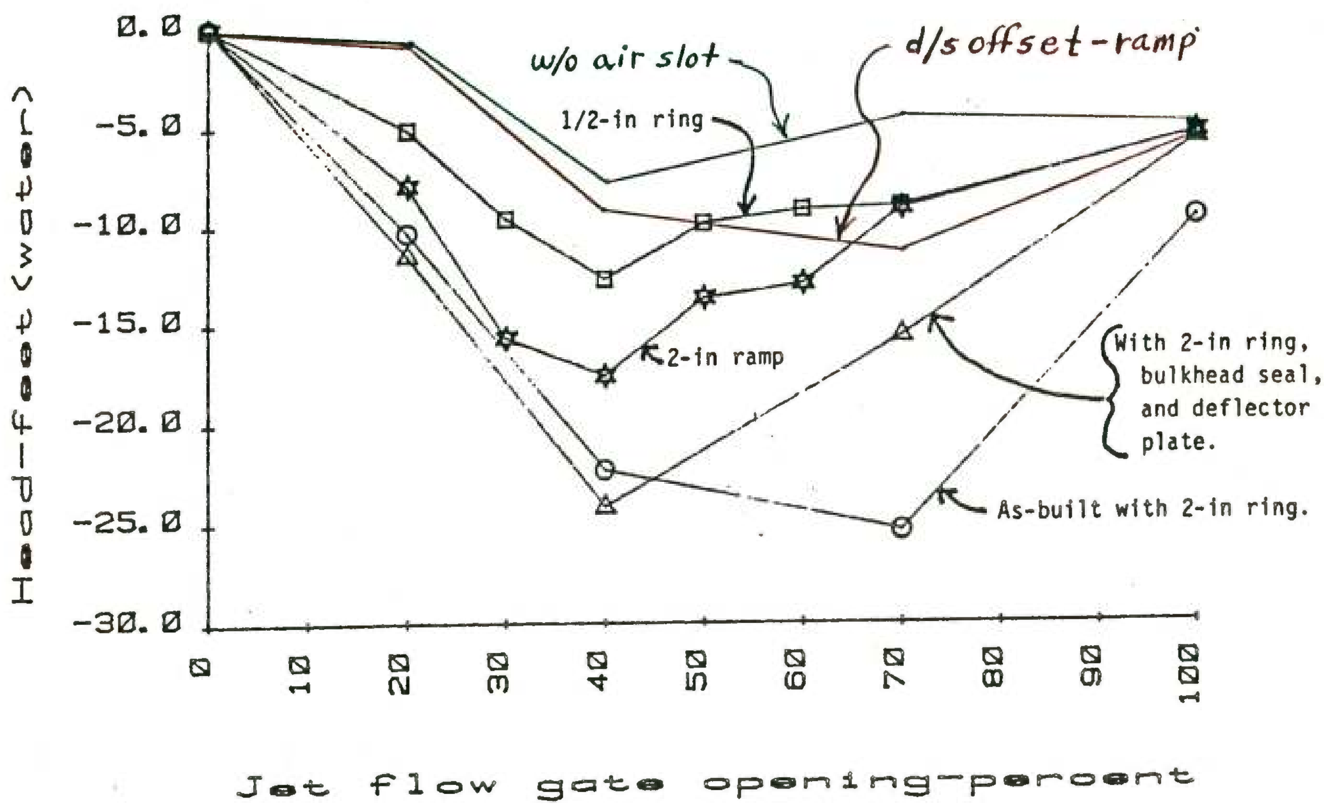


Figure 10. - Average static air pressure head inside upstream end of aluminum air duct (P13) vs. gate opening.



(a) Immediately downstream of air slot
(maximum of P9b, P9c, or P9d)



(b) Downstream of air slot at end of steel liner
(maximum of P10a through P10j)

Figure 11. - Average side wall pressure head at (a) immediately downstream of air slot and (b) at end of steel liner vs. gate opening.

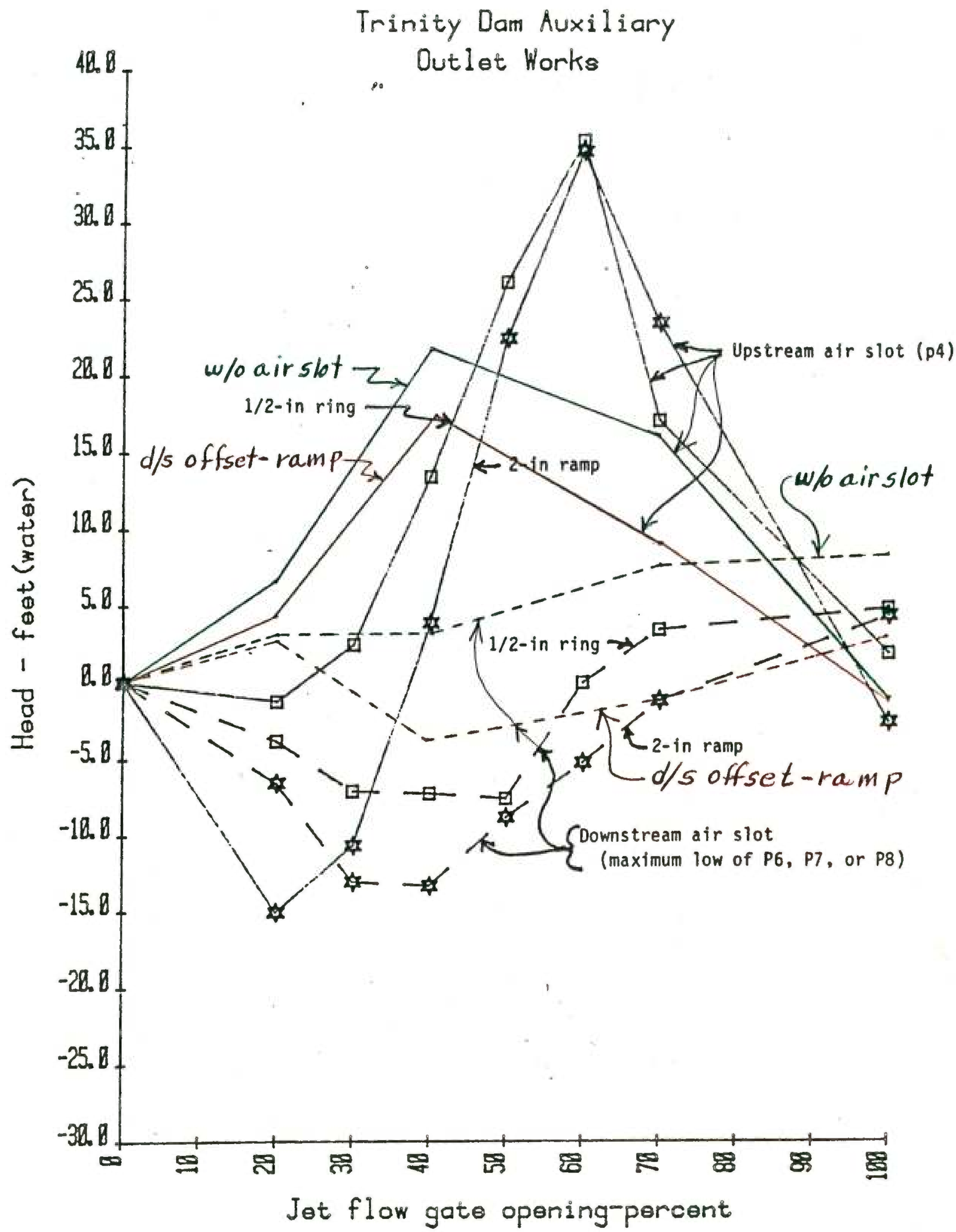


Figure 13. - Average invert pressure head upstream and downstream of air slot vs. gate opening.

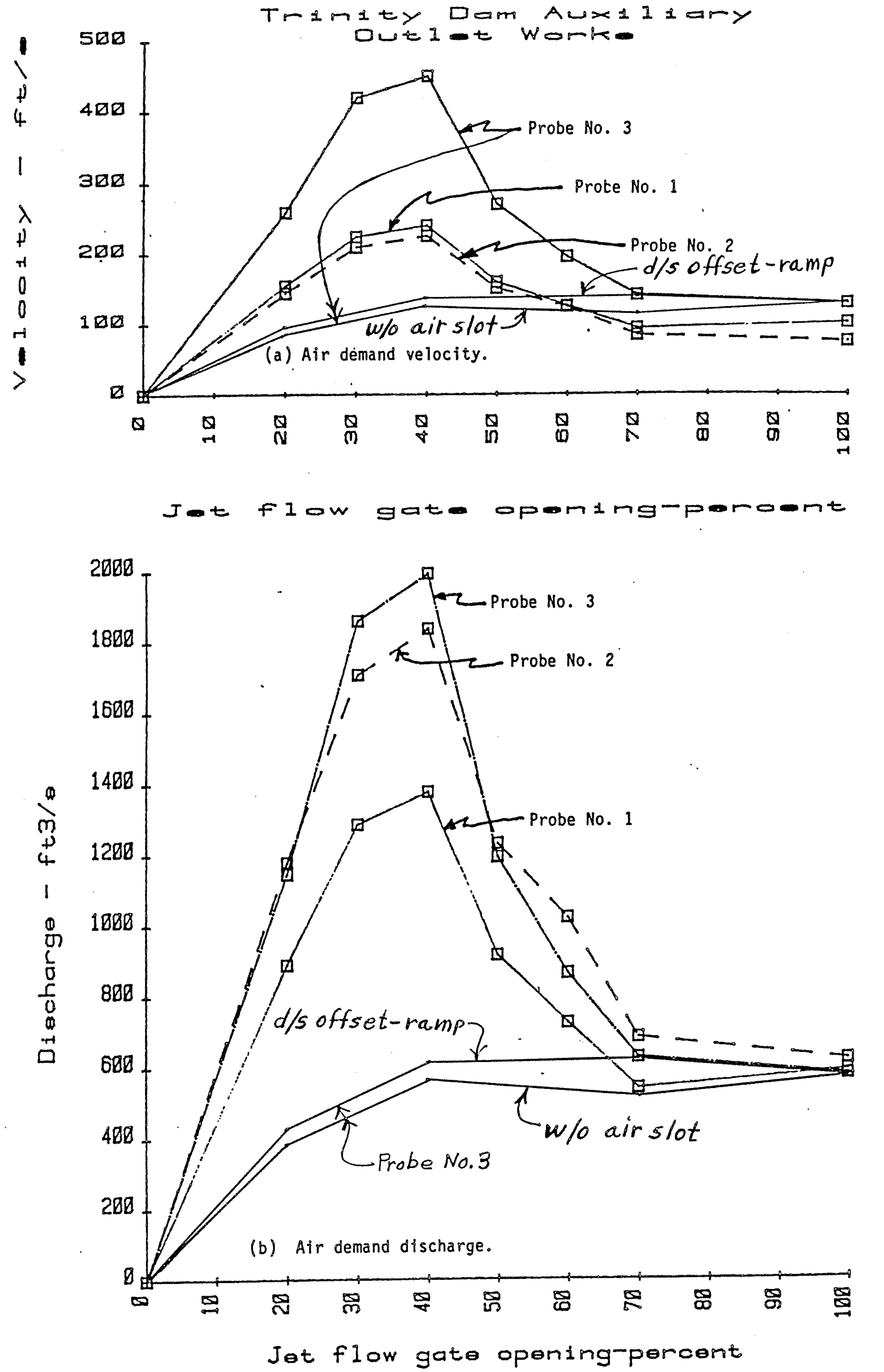


Figure 15. - Air demand (a) velocity and (b) discharge at the three air velocity probe locations based on 1/2-in-high orifice ring offset configuration vs. gate opening.